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AKCE International Journal of Graphs and Combinatorics

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/uakc20

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To cite this article: Robin Wilson (2020) Working with Lowell, AKCE International Journal of Graphs and Combinatorics, 17:2, 641-645, DOI: 10.1080/09728600.2020.1834338

To link to this article: https://doi.org/10.1080/09728600.2020.1834338

AKCE INTERNATIONAL JOURNAL OF GRAPHS AND COMBINATORICS
2020, VOL. 17, NO. 2, 641–645
https://doi.org/10.1080/09728600.2020.1834338

Working with Lowell

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ABSTRACT

I have known Lowell Beineke for almost fifty years. Our first joint paper, on edge-colorings of graphs, was initiated in 1971, and since then we have produced further articles and nine books on graph theory, with another two books currently in progress. In this note I present some personal reminiscences and describe our collaborations over these years, as graph theory and combinatorics expanded from minority interests to a central part of contemporary mathematics.

KEYWORDS

Graph theory; combinatorics; applications of graph theory

1. Setting the scene

Lowell Beineke received his B.S. degree from Purdue University in 1962 and proceeded to M.S and Ph.D. degrees at the University of Michigan, receiving his doctorate in 1965 for a thesis entitled "On the decomposition of complete graphs into planar and other subgraphs" under the supervision of Frank Harary. In the same year he accepted a position at Purdue University at Fort Wayne, where he has remained ever since, holding the Jack W. Schrey Chair of Mathematical Sciences. In 1966 he attended a graph theory conference in Tihany, Hungary, and the International Congress of Mathematicians in Moscow, and spent the following academic year at University College, London, the first of five sabbatical years spent in England. His celebrated forbidden-subgraph characterization of line graphs was published in 1968, and since then he has written over 100 papers in graph theory and related subjects.

Meanwhile, I had received my B.A. degree from Oxford University in 1965, to be followed by three years of graduate study at the University of Pennsylvania and MIT, leading to a Ph.D. degree for a thesis on number theory. But during my year at MIT I became excited by a course on combinatorial theory given by Gian-Carlo Rota and decided to switch areas as soon as my thesis was finished. I then spent the academic year 1968–69 at Cambridge University learning my new subject before being appointed to a lectureship at Jesus College, Oxford University.

At that time an explosion of activity in graph theory and combinatorics was taking place. The first graph theory conference had been held in Dobogókő in Hungary in 1959, followed by combinatorial conferences in Germany, the USA, Czechoslovakia, Italy, and Canada. The first Chapel Hill combinatorial conference took place in 1967 and the first quadrennial Kalamazoo graph theory conference was held in the following year, with the first Southeastern Conference following on in 1970. The subject was also beginning to take hold in universities, where courses were beginning to spring up, including one in Oxford in 1969, which I taught. The first British Combinatorial Conference had been held in Oxford earlier in the same year.

Books on graph theory were also beginning to appear. Among these were the classic texts of Claude Berge (1958) and Oystein Ore (1962), as well as books on specific topics by Gerhard Ringel (1959), John Moon (1968), and others, and the *Journal of Combinatorial Theory* made its first appearance in 1966. A landmark was the appearance of Frank Harary's *Graph Theory* in 1969, and in 1972, finding the need for an elementary and inexpensive book on graph theory for undergraduates, I wrote my *Introduction to Graph Theory*, which is still widely used.

2. Our first meeting

Lowell Beineke and I first met on July 4th, 1971, at a summer course on combinatorics at Bowdoin College in Brunswick, Maine, organized by Gian-Carlo Rota. John Moon, who was spending the year in Oxford, told me that he thought that Lowell and I would get on well together, so I introduced myself to him. My wife Joy and I quickly became good friends of Lowell and his English wife Judith (see Figure 1), who were there with their one-year-old daughter Jennie (now a professor of number theory in Connecticut).

Lowell and I discussed writing a joint paper at the meeting. I had been intrigued by a remark in Harary's book that simple graphs with maximum degree have

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Figure 1. Lowell and Judith Beineke in the 1960s.

Figure 2. Lowell with Frank Harary.

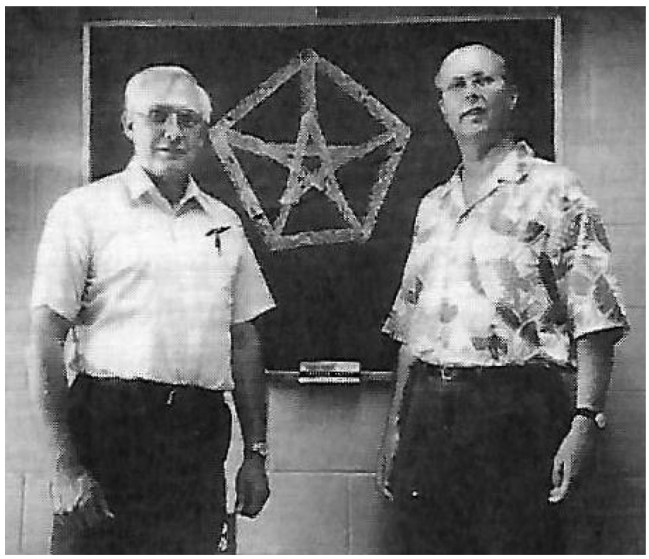


Figure 3. Lowell, me, and the Petersen graph.

chromatic index Δ or $\Delta+1$ (Vizing's theorem), but that it was not known which graphs needed the extra color. We decided to investigate this, and the result was our 1973 paper "On the edge-chromatic number of a graph" [3] which, although not dramatic in content, managed to inspire others to look at edge-colorings of graphs in general, as we shall see.

3. A year in Oxford

The academic year 1973–74 was a good time for graph theory at Oxford University, when Lowell arrived with Frank Harary (see Figures 2 and 3), Ed Palmer, and Allen Schwenk to spend the year at the Mathematical Institute. In 1972 I had moved to a position at the UK's Open University and had taken on my first research student, Stanley Fiorini, and before long Lowell and Stanley had written a joint paper on edge-colorings. I also arranged for Lowell to give a plenary lecture at the British Mathematical Colloquium, and we both attended a graph theory conference in Prague for which we wrote a joint survey on tournaments [4]. Stanley was later to receive the first doctorate in pure mathematics from the Open University for his work on edge-colorings.

4. *Selected Topics in Graph Theory* and *Applications of Graph Theory*

It was during Lowell's visits to the UK, and to British Combinatorial Conferences, that we conceived the idea of a book of surveys in the rapidly expanding area of graph theory, to be written by experts in the field. Entitled *Selected Topics in Graph Theory* its chapters would be edited for readability, with the terminology and notation standardized throughout (see Figure 4). The topics ranged from topological graph theory and tournaments to minimax theorems and the recently proved four color theorem, and the invited authors were Jean-Claude Bermond, Peter Cameron, Stanley Fiorini, Brooks Reid, Bob Hemminger, Crispin Nash-Williams, Ed Palmer, Tory Parsons, Ron Read, Allen Schwenk, Art White, and Douglas Woodall. The book was published by Academic Press in 1978 [5] and was selected by *Choice Magazine* as "one of the top six mathematics books for 1979."

The success of these books led us to produce two further volumes of "Selected Topics" in 1983 and 1988 [6, 7], with an impressive range of distinguished authors, including Claude Berge, Bill Tutte, László Lovász, Carsten Thomassen, Tom Trotter, Miklós Simonovitz, Richard Guy, Dominic Welsh, Fan Chung, and Ron Graham. As before, these chapters were heavily edited, and some authors must have been irritated on seeing their "perfect" chapter drafts covered with red ink! But a number of them have since conceded that the final product was better than they would

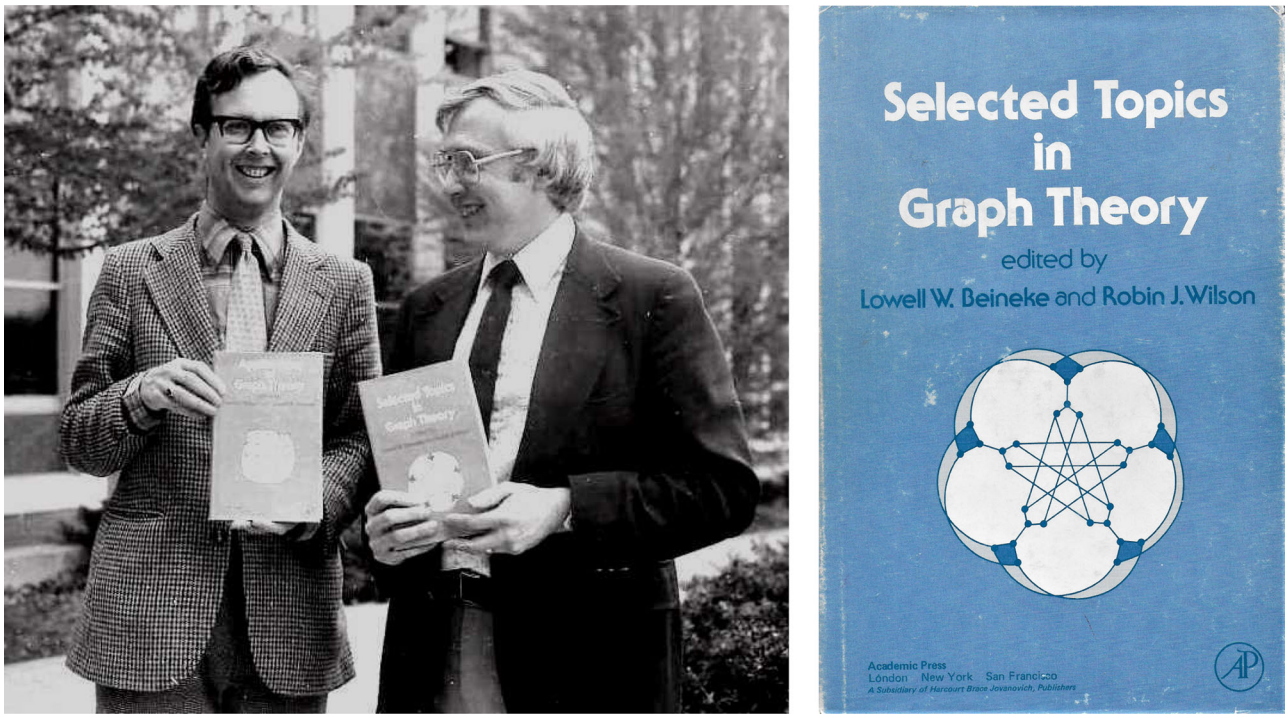


Figure 4. *Selected Topics in Graph Theory.*

have produced on their own—and we certainly could not have written the chapters without their knowledge and expertise. Around the same time as the first selection, we also decided on a similar set of surveys entitled *Applications of Graph Theory* [15]. It appeared in 1979 and included surveys on such topics as communication and electrical networks, statistical mechanics, chemistry, operations research, geography, architecture, linguistics, and the social sciences.

5. The middle years

From 1980 onwards Lowell and I managed to see each other regularly, with Lowell and Judith visiting Oxford regularly during the early summer, frequently also attending British Combinatorial Conferences—indeed, Lowell was one of the invited plenary speakers at the 1981 BCC in Swansea during a year he spent at the Polytechnic of North London. I was also able to visit him and Judith at Fort Wayne on several occasions to give lectures—and on one occasion at Thanksgiving to be the disk jockey on a local radio program on the operas of Gilbert and Sullivan! I also attended several AMS–MAA Joint Winter Meetings where we were able to catch up with each other, and at one of these occasions Lowell participated in a play that I had written on the mathematical activities of Lewis Carroll, together with his daughter Jennie (who played Alice).

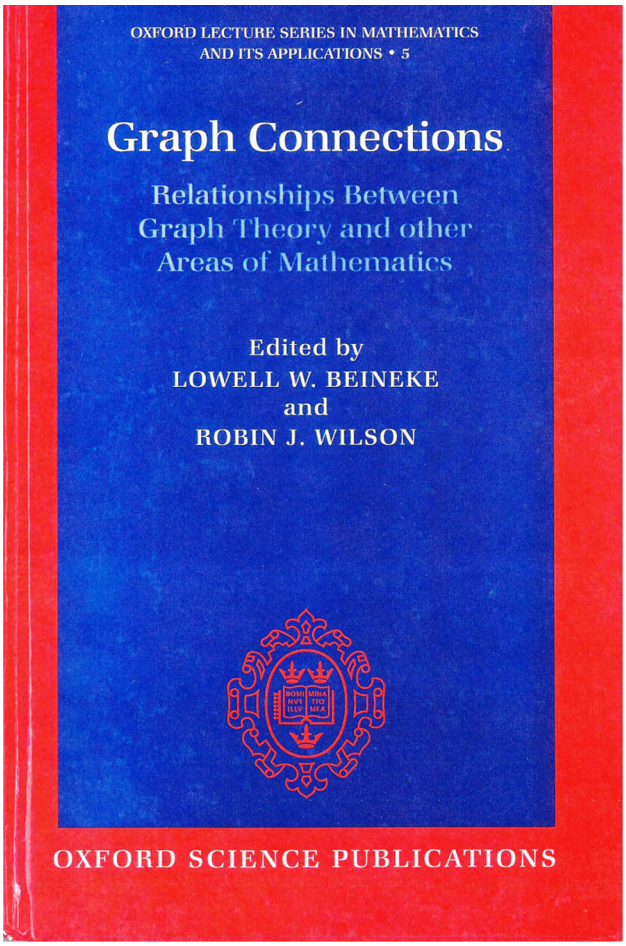
In the early 1990s we conceived the idea of a book on the relationships between graph theory and other areas of mathematics, and this resulted in *Graph Connections* [8] (see Figure 5), with chapters describing the links with such areas as algebra, number theory, logic, topology, geometry, coding theory, probability, and mathematical finance. This book was published in 1997 by Oxford University Press.

6. The "Topics" books

By 2000, graph theory had expanded so much, and the subject had become so much more technical, that the earlier survey books seemed no longer to serve their purpose. This led Lowell and me to conceive of a trilogy of books entitled *Topics in – Graph Theory*, where we would focus on surveys covering just one particular area. Because we did not have the expertise in these areas, each volume has an academic consultant who advises us on the important topics to be covered and on who should be approached to write them.

The first book in this new series, published by Cambridge University Press, was *Topics in Algebraic Graph Theory* [9], published in 2004 with Peter Cameron as the academic consultant. This was followed in 2009 by *Topics in Topological Graph Theory* [10], with Jonathan L. Gross and Thomas W. Tucker as consultants, and in 2012 by *Topics in Structural Graph Theory* [11], where we benefited from the advice of Ortrud R. Oellermann.

Producing such books tends to become a habit, and the fourth book in the "trilogy"—*Topics in Chromatic Graph Theory* [12] (see Figure 5), with Bjarne Toft as our consultant, duly appeared three years later. A fifth book is currently with the publisher, on *Topics in Algorithmic Graph Theory* [1], with Martin Golumbic as collaborator, and there may possibly be yet one more volume to follow.



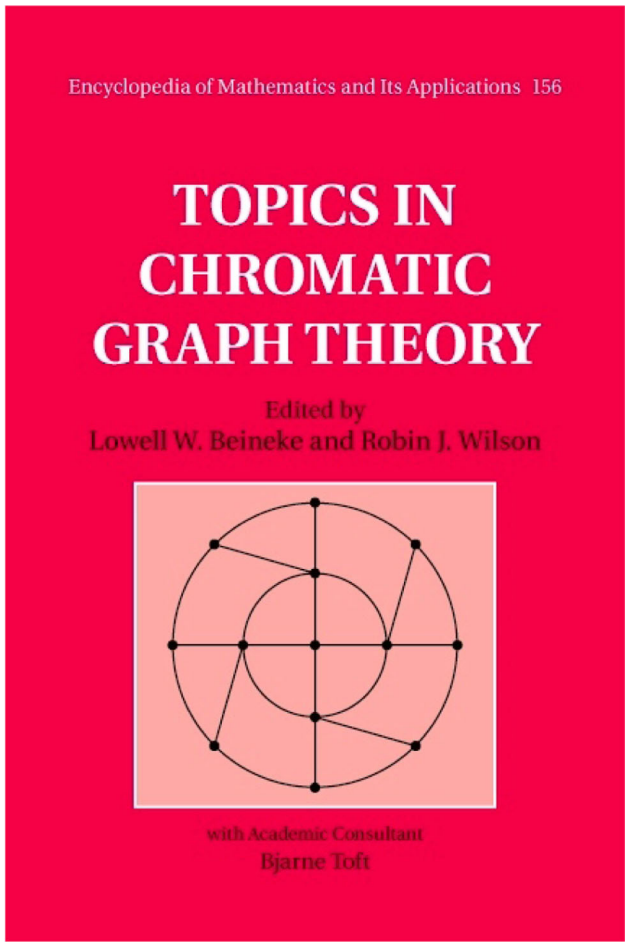


Figure 5. *Graph Connections* and *Topics in Chromatic Graph Theory*.

Whether or not this happens, it has been exciting to work in collaboration with more than one hundred graph theorists from around the world over many years.

7. Milestones in graph theory

These survey volumes have not been our only collaboration. As well as our three papers in the 1970s [3, 4, 14], and a joint article on the history of crossing numbers in 2010 for *The Mathematical Intelligencer* [13], we have for a long time been working on a major project entitled *Milestones in Graph Theory* [2], in which we present sixty papers from the 20th century that have been crucial in the development of the subject. These have been translated into English where necessary, and will appear with a commentary that is designed to place each paper in its mathematical and historical context. With over 500 papers that we looked at before making our selections, we decided to collaborate with a third author, Bjarne Toft. This project is now nearing its conclusion, and we hope that it will be published within the next couple of years.

Figure 6. Lowell and me.

8. Conclusion

Collaborating with Lowell Beineke on all these projects has been an important part of my academic life, as well as a great joy. We tend to think alike on most matters of style, while our few disagreements have tended to strengthen our friendship rather than to weaken it. We may not have fifty more years of collaboration in the future, but we still find

Figure 7. Lowell, Judith, and Jennie.

projects to work on together while we have much to look back on with satisfaction (see Figures 6 and 7).

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